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ADVISORY CIRCULAR

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

SUBJECT: THUNDERSTORMS

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1. PURPOSE. This advisory circular provides additional information to that contained in AC 90-12; SUBJECT: SEVERE WEATHER AVOIDANCE, dated April 15, 1964.

2. DISCUSSION. In view of the impact of severe storms on safe and efficient flight, we asked the Director, National Severe Storms Laboratory, U.S. Department of Commerce, Environmental Science Services Administration, to provide this agency with his over-all evaluation of what is now known about this important problem. NSSL research has been supported in part by FAA and other agencies.

   Due to difficulties associated with (1) the collection of accurate and comprehensive flight data and the period of one or two years required to reduce data and publish analyses, and (2) the urgent nature of the problems besetting flights through or near thunderstorms, the information given here includes preliminary findings which may be revised during the course of continuing studies.

   The NSSL research has been accomplished during the years 1964 through 1967 utilizing only Oklahoma type thunderstorms; however, we believe that the NSSL comments are applicable in some degree to other geographically located thunderstorms (see section 3.1. below). The following comments/discussion are based on that type of air turbulence that can be expected in relation to radar returns on USWB ground-based radar. This description of what USWB radar meteorologists view and interpret on their radar is intended to provide pilots an insight concerning the availability of radar weather information that can be helpful when preparing for a flight or while en route.

Initiated by: AFS-224

Paragraph 3 constitutes the NSSL's interpretation of information and experience available to date as a result of research and controlled thunderstorm penetrations by specially equipped high performance aircraft.

No firm rule to avoid thunderstorm cells by a definite number of miles can be given; however, the pilot must exercise good judgment based on knowledge of thunderstorm characteristics to accomplish his flight safely.

3. NSSL COMMENTS ON FLIGHT IN AND NEAR THUNDERSTORMS.

a. The relationships between turbulence and altitude.

The NSSL studies of Oklahoma thunderstorms extending to 60,000 feet show little variation of turbulence intensity with altitude.

b. Turbulence and echo intensity on USWB radar (WSR-57).

The frequency and severity of turbulence increases with the radar reflectivity, a measure of the intensity of echoes from storm targets at a standard range. Although pilots and air traffic specialists may be unfamiliar with the reflectivity factor, this quantity provides a logical basis for interpretation of U.S. Weather Bureau radar displays and associated turbulence. Derived gust velocities exceeding 35 feet per second (classified as severe turbulence) are commonly encountered in storms whose maximum reflectivity factor is 10^4 or more. In storms whose peak intensity is about 10^3, gusts of intensity between 20 and 35 feet per second (classified as moderate turbulence) are encountered approximately once for each 10 nautical miles of flight.

c. Turbulence in relation to distance from storm core.

NSSL data indicate that the frequency and severity of turbulence encounters decrease slowly with distance from storm cores. Significantly, the data indicate that 20 miles from the center of severe storm cores, moderate to severe turbulence is encountered at any altitude about one-fifth as often as in the cores of severe storms whose radar reflectivity factor Z exceeds 10^4. Further, the data indicate that moderate to severe turbulence is encountered at any altitude up to 10 miles from the center of less severe storm cores whose reflectivity factors Z lie between 10^3 and 10^4. SEVERE TURBULENCE IS OFTEN FOUND IN TENUOUS

ANVIL CLOUD 15 TO 20 MILES DOWNWIND FROM SEVERE STORM CORES.

Our findings agree with meteorological reasoning that THE STORM CLOUD IS ONLY THE VISIBLE PORTION OF A TURBULENT SYSTEM WHOSE UPDRAFTS AND DOWNDRAFTS OFTEN EXTEND OUTSIDE OF THE STORM PROPER.

d. Turbulence in relation to distance from the storm edge.

THE CLEAR AIR NEAR AN OKLAHOMA STORM IS A PLACE WHERE SEVERE TURBULENCE MAY OCCUR, somewhat more often on the storm's downwind side. At the edge of a cloud, the mixing of cloudy and clear air often produces strong temperature gradients associated with rapid variations of vertical velocity.

Tornadic activity is found in a wide range of spatial relationships to the strong echoes with which they are commonly associated, but many of the most intense and enduring occur on the south to west edges of severe storms, i.e., on the up-relative-wind side. The air rising in a tornado can contribute to a downwind area of strong echo(s) while the tornado itself is often associated with a weak echo or no echo. Echo hooks and appendages are useful qualitative indicators of tornado occurrence but are by no means infallible guides.

Severe turbulence should be anticipated up to 20 miles from the severe storms; these often have a well defined radar echo boundary. This distance decreases to approximately 10 miles with weaker storms which sometimes have indefinite radar echo boundaries. THEREFORE, AIRBORNE RADAR IS A PARTICULARLY USEFUL AID FOR PILOTS IN MAINTAINING A SAFE DISTANCE FROM SEVERE STORMS.

e. Turbulence above storm tops.

Limited flight data shows there may be a relationship between turbulence above storm tops and the speed of upper tropospheric winds. WHEN THE WINDS AT STORM TOP EXCEED 100 KNOTS, THERE ARE TIMES WHEN SIGNIFICANT TURBULENCE MAY BE EXPERIENCED AS MUCH AS 10,000 FEET ABOVE THE CLOUD TOPS. THIS VALUE MAY BE DECREASED 1000 FEET FOR EACH 10 KNOT REDUCTION OF WIND SPEED. This is especially important for clouds whose height exceeds the height of the tropopause. It should be noted that flight above severe thunderstorms is an academic consideration for today's civil aircraft in most cases, since these storms usually extend to 40,000 feet, and above. Considerations of overflight will be more important as supersonic transports are introduced.

f. Turbulence below cloud base.

While there is a little evidence that maximum turbulence exists at middle heights in storms (FL 200-300), turbulence beneath a storm is not to be minimized. This is especially true when the relative humidity is low in any air layer between the surface and 15,000 feet. Then the lower altitudes may be characterized by strong outflowing winds and severe turbulence where thunderstorms are present. Therefore, THE SAME TURBULENCE CONSIDERATIONS WHICH APPLY TO FLIGHT AT HIGH ALTITUDES NEAR STORMS APPLY TO LOW LEVELS AS WELL.

g. Maximum storm tops.

Photogrammetric data indicate that the maximum height attained by Oklahoma thunderstorm clouds is approximately 63,000 feet. Such very tall storm tops have not been explored by direct means, but meteorological judgments indicate the probable existence of large hail and strong vertical drafts to within a few thousand feet of the top of these isolated stratosphere-penetrating storms. THEREFORE, IT APPEARS IMPORTANT TO AVOID SUCH VERY TALL TOWERS AT ALL ALTITUDES.

h. Hail in thunderstorms.

The occurrence of HAIL IS MUCH MORE CLEARLY IDENTIFIED WITH THE INTENSITY OF ECHOES THAN IS TURBULENCE. AVOIDANCE OF MODERATE AND SEVERE STORMS SHOULD ALWAYS BE ASSOCIATED WITH THE AVOIDANCE OF DAMAGING HAIL.

i. Temperature variations near storms.

The greatest temperature variations occur along the edges of clouds in a dry environment and near the summits of tropopause - penetrating storms. In these places, temperature changes and turbulence are statistically associated. TEMPERATURE CHANGES

AS GREAT AS 10° C/MILE HAVE BEEN MEASURED NEAR SEVERE STORMS AND GRADIENTS OF 3° - 4°C PER MILE ARE FAIRLY COMMON.

j. Visual appearance of storms and associated turbulence within them.

On numerous occasions, flights at NSSL have indicated that NO USEFUL CORRELATION EXISTS BETWEEN THE EXTERNAL VISUAL APPEARANCE OF THUNDERSTORMS AND THE TURBULENCE AND HAIL WITHIN THEM.

k. Modification of criteria when severe storms and rapid development are evident.

During severe storm situations, radar echo intensities may grow by a factor of ten each minute, and cloud tops by 7,000 feet per minute. THEREFORE, NO FLIGHT PATH THROUGH SUCH A FIELD OF STRONG OR VERY STRONG STORMS SEPARATED BY 20-30 MILES OR LESS MAY BE CONSIDERED FREE FROM SEVERE TURBULENCE.

l. Extrapolation to other climes.

General comment: Oklahoma is noted for its severe storms. The attention of the meteorologist and the pilot is drawn also to the relatively frequent occurrence in Oklahoma of an atmospheric stratification marked by large values of moisture in low levels, relative dryness in middle levels and strong wind shear. It is well known that this stratification of moisture permits excessive magnitudes of convective instability to exist for an indefinite period until rapid overturning of air is triggered by a suitable disturbance. Regions of the atmosphere which are either very dry or very moist throughout substantial depths cannot harbor great convective instability. Rather, a more nearly neutral thermal stratification is maintained, partially through a process of regular atmospheric overturning. This greatly simplified picture permits a cautious generalization of the Oklahoma experiences.

Desert areas - In desert areas, storms should be avoided on the same basis as described for Oklahoma. While non-storm turbulence may in general be expected more frequently over desert areas during daylight hours than elsewhere, THE SAME TURBULENCE CONSIDERATIONS PREVAIL IN THE VICINITY OF THUNDERSTORMS.

Tropical - humid climates - When the atmosphere is moist and only slightly unstable through a great depth, strong radar echoes may be received from towering clouds which do not contain vertical velocities as strong as those of storms over the U.S. plains. Then it is a matter of the pilot being informed with respect to the general atmospheric conditions accompanying storms, for it is well known that PRACTICALLY ALL GEOGRAPHIC AREAS HAVING THUNDERSTORMS ARE OCCASIONALLY VISITED BY SEVERE ONES.

m. Interpretation of radar messages from U.S. Weather Bureau (WSR-57 ground-based radar).

As mentioned in paragraph 3.b., the intensity categories noted in messages disseminated by the U.S. Weather Bureau are related approximately to the categories of reflectivity factor Z discussed above. Moderate echoes are associated with reflectivity factors Z between 10^3 and 10^4, and moderate to severe turbulence may be found within 10 miles of the storms. Echoes reported as strong and very strong are associated with Z factors of 10^4 and greater and signify potentially severe turbulence within 20 miles of the storms.

n. Use of airborne radar.

Airborne radar is a valuable tool; HOWEVER, ITS USE IS PRINCIPALLY AS AN INDICATOR OF STORM LOCATIONS FOR AVOIDANCE PURPOSES WHILE EN ROUTE.

4. PILOT ADVISORY SERVICE.

As information becomes available based on results of radar weather research and actual thunderstorm penetrations, this circular will be updated or supplemented. Through intensive research we are attempting to provide the air traffic control system with the capability to locate, identify and measure the intensity of turbulence associated with severe weather so that we can accurately advise pilots of weather that should be avoided.

James F. Rudolph
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